chapter

22 Population Changes

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Populations of organisms are dynamic (**Figure 1**). Some populations, such as those of the African black rhinoceros and the Vancouver Island marmot, are in serious decline and threatened with imminent extinction unless drastic action is taken. Other populations, such as those of the California sea lion along the west coast of North America and the cane toads in Australia, are experiencing unprecedented growth. While the number of chimpanzees, our closest living relative, has declined from about 2 million in 1900 to less than 150 000 at present, our own population has increased by more than 4 billion in the same time frame.

Can the extinction of entire species be avoided? What are the consequences of rapid population growth? To answer these questions, biologists must study populations carefully and observe and monitor changing environmental conditions. Changes in population numbers and in the patterns of distribution of individuals can have direct effects on the local ecosystem and may affect the well-being of other species within the ecological community.

Population ecologists use specialized methods to monitor, quantify, and model changes in populations. They also study the interrelationships between different species. In this way, they gather data necessary to predict future trends in the growth of populations. This information can be used to assess the health of individual species and entire ecosystems, to develop policies and plans of action to save species from extinction, and to address the impacts of rapidly growing populations.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

Study **Figure 1** on the next page and reflect on the following:

1. What relationships might exist among these animals?
2. List and explain factors in this environment that might be responsible for the organisms present there.
3. What conditions in ecosystems and which activities by human and other animals might affect the number of individuals within each population?
4. How would you measure the change in each population over time?

Career Connections:
Ecologist; College, Technical, or Vocational Instructor

Figure 1
The size of the various populations in an area, such as those that come to this watering hole, changes over time. Population ecologists have developed a number of methods of quantifying these changes.

Exploration — Moving Populations

While the populations of many species remain in the same general area all the time, the populations of some species migrate. Each fall, 120 million red land crabs on Christmas Island migrate overland to the coast to mate and lay their eggs (**Figure 2**).

(a) What are the advantages of all the crabs migrating and breeding at precisely the same time each year?
(b) What are the disadvantages to such a strategy?
(c) Each female crab lays about 100 000 eggs, whereas many animal species produce far fewer young. What are the advantages and disadvantages of producing so many offspring? Do you think a high birth rate guarantees population growth?
(d) How might the size of the red crab population fluctuate during the course of a year? Would you expect this pattern to be typical or unusual for wild populations?
(e) If you were a biologist trying to determine if the population was increasing or decreasing over the long term, what challenges would you face?

Figure 2
Red land crabs

22.1 Characteristics of Populations

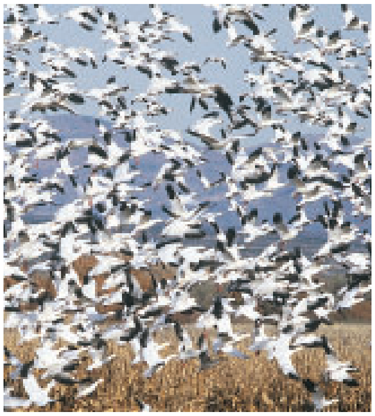

Figure 1
Greater snow geese are endangering their own survival by exceeding the carrying capacity of the natural marshes along the St. Lawrence River during their migration.

Canadian wildlife biologists have expressed concern over the increase in the greater snow goose population in the eastern Canadian Arctic from 50 000 in the late 1960s to about 950 000 in 2004 (**Figure 1**). The presence of increasing numbers of these snow geese has affected other species within the habitat. Overgrazing has caused widespread damage to the vegetation of Arctic coastal sites, resulting in a decline in the abundance of other bird and wildlife species that also depend on these habitats for resources. In the fall, the snow geese migrate south, stopping to feed on agricultural crops in central and eastern Canada and the United States, so many farmers regard the geese as pests. Members of the Arctic Goose Habitat Working Group, a consortium of Canadian and American wildlife biologists, have recommended that, to decrease damage to Arctic ecosystems, the total population of this species be reduced. How do biologists count huge populations of birds that migrate each fall, produce young each spring, and die at different times? How can they determine what population size might be ideal for a particular habitat and how can they tell when a population reaches this ideal size?

Population Size and Density

To study populations, scientists measure such characteristics as **population size**, or the estimated total number of organisms, as well as the density and dispersion of organisms within their habitat. The **population density** (D_p) of any population is calculated by dividing the total numbers counted (N) by the area (A) or volume (V) occupied by the population. For example, the population density of 480 bison living in a 600 hectare (ha) region of Wood Buffalo National Park would be calculated as follows:

$$D_P = \frac{N}{A} \quad \text{or} \quad D_P = \frac{N}{V}$$

$$D_P = \frac{480 \text{ bison}}{600 \text{ ha}}$$

$$= 0.800 \text{ bison/ha}$$

population size the number of individuals of a specific species occupying a given area/volume at a given time

population density the number of individuals of the same species that occur per unit area or volume

Populations vary widely among different species occupying different habitats. As shown in **Table 1**, small organisms usually have higher population densities than larger organisms. These widely ranging densities pose different challenges to biologists attempting to gather data on a particular species. Population density can be deceiving because of unused or unusable space within a habitat. For example, the bison in Wood Buffalo National Park do not use areas that are open lake water.

Table 1 Examples of Population Densities

Population	Density
jack pine	380/ha
field mice	250/ha
bison	0.800/ha
soil arthropods	500 000/m^2
phytoplankton (in a pond)	4 000 000/m^3

Learning Tip

You can calculate population density using either area or volume.

$$D_p = \frac{N}{A} \quad \text{or} \quad D_p = \frac{N}{V}$$

where D_p is population density, N is number of individuals, and A is area or V is volume

Practice

1. Calculate the density of a population of painted turtles (**Figure 2**) if 34 turtles were counted in a 200 ha park.

Figure 2
A painted turtle

2. Speculate about areas within the park that might not be used by the painted turtles.
3. Suggest a possible proportion (%) of the park that is not used by the turtle. Use the proportion that you think is used by the turtles to calculate a density value. This value is referred to as the **ecological density**.
4. A student counts 56 mosquito larvae in a 2 L sample of water from a local pond. Calculate the density of the mosquito population per litre and per cubic metre of pond water.

ecological density population density measured in terms of the number of individuals of the same species per unit area or volume actually used by the individuals

WWW WEB Activity

Canadian Achievers—Dr. Stephen Herrero

Ecologists use many techniques to determine population size, density, and growth. One such ecologist is Dr. Stephen Herrero, a professor emeritus of environmental science at the University of Calgary (**Figure 3**). Dr. Herrero specializes in wildlife ecology and conservation biology with a special interest in the ecology of large predators—most notably grizzly bears. Learn more about Dr. Herrero and his research on grizzly bears in the eastern Rockies. Write a report or make a presentation that explains how Dr. Herrero uses knowledge of population size, density, and growth to improve grizzly bear management and conservation efforts.

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Figure 3
Dr. Stephen Herrero

Environmental conditions and suitable habitats differ throughout a population's geographic range. For this reason, the **population dispersion** of groups of organisms within a population varies throughout the range. Biologists have identified three main dispersion patterns among wild populations: clumped, uniform, and random. Most populations exhibit patchy or **clumped dispersion**, in which organisms are densely grouped in areas of the habitat with favourable conditions for survival. Cattails exhibit clumped dispersion. They are usually restricted to growing along the edges of ponds and lakes, or in other wet soils. Clumped dispersion may also be the result of social behaviour, such as fish swimming in large schools to gain protection from predators, as shown in **Figure 4 (a)** on the next page.

population dispersion the general pattern in which individuals are distributed through a specified area

clumped dispersion the pattern in which individuals in a population are more concentrated in certain parts of a habitat

uniform dispersion the pattern in which individuals are equally spaced throughout a habitat

random dispersion the pattern in which individuals are spread throughout a habitat in an unpredictable and patternless manner

Other organisms exhibit **uniform dispersion** in which individuals are evenly distributed throughout the habitat. This pattern may result from competition between individuals that set up territories for feeding, breeding, or nesting. When King penguins nest on South Georgia Island in the South Atlantic Ocean, they often exhibit a nearly uniform dispersion pattern, as shown in **Figure 4** (**b**). Although wild species rarely exhibit uniform dispersion, the plants in crop fields, orchards, and tree plantations are often uniformly dispersed.

Individuals exhibit **random dispersion** when they are minimally influenced by interactions with other individuals and when habitat conditions are also virtually uniform. As shown in **Figure 4** (**c**), some species of trees in tropical rain forests exhibit random dispersion, although this pattern is also rare in nature.

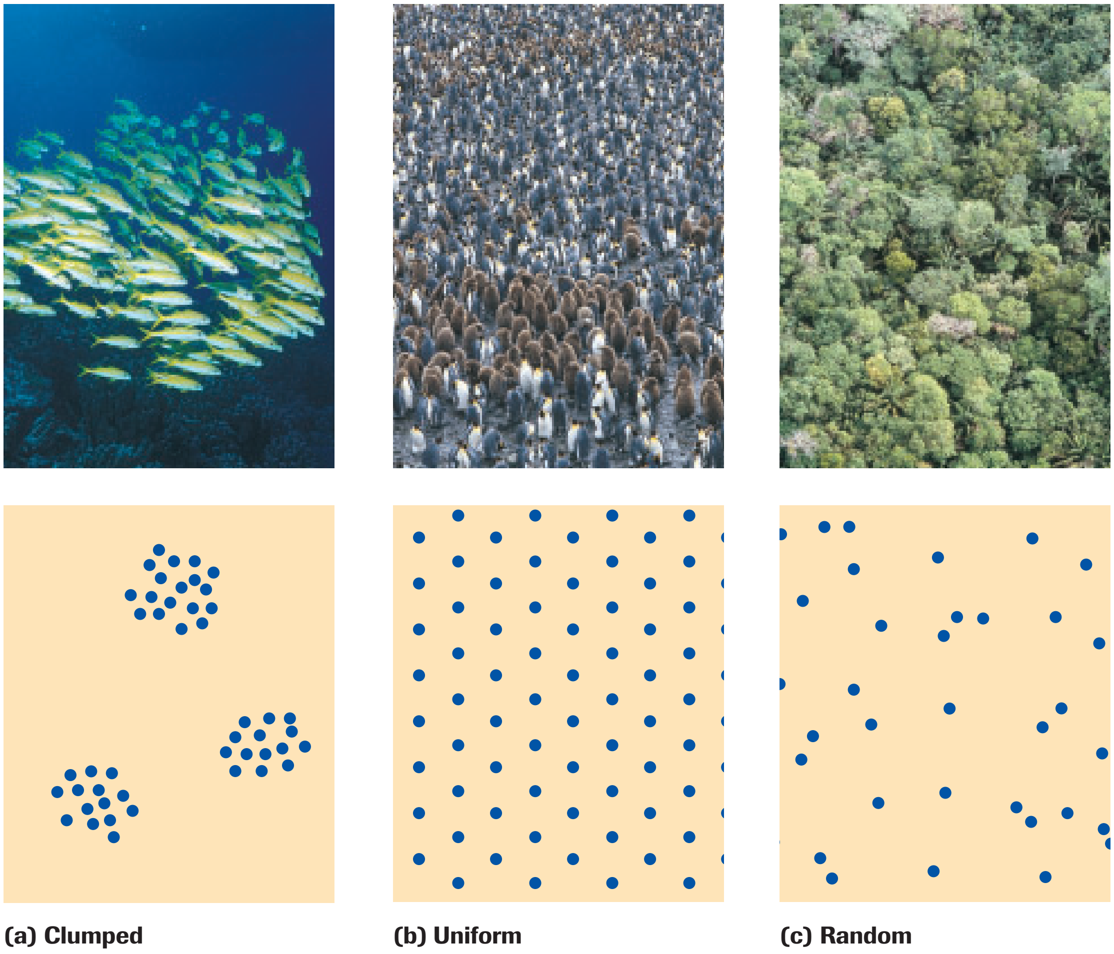

Figure 4
Populations generally exhibit one of three patterns of dispersion:
(a) Yellow goatfish are often found clumped in schools.
(b) Nesting King penguins exhibit a uniform pattern.
(c) In tropical rain forests, trees of the same species may be randomly dispersed.

WWW **WEB Activity**

Case Study—Wildlife Tracking

It is often difficult to determine the range and distribution of wildlife over long periods of time. While many organisms are easy to observe during parts of the year or parts of their life span, they may be very difficult to locate at other times. For example, it is easy to observe sea turtles when they come ashore to lay eggs, but harder to find where they travel and feed in the open ocean. It is easy to observe Alberta's breeding birds in the spring and summer, but much more difficult to determine their migration routes and winter range. Many species pose similar challenges. Beginning in 1937, researchers Fred and Norah Urquhart annually marked monarch butterflies in an attempt to discover the wintering location of this migratory species. In 1975, they finally discovered it.

In this activity, you will conduct research to explore the science of marking and releasing organisms.

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EXTENSION

Mark-Recapture Method

In this animation, you will apply this method of estimating population size to virtual butterflies.

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SUMMARY Characteristics of Populations

- Biologists use different measurements, such as population size and population density, to describe and monitor populations.
- Populations in a given geographical range exhibit one of three distinct dispersion patterns: clumped, uniform, or random.

Section 22.1 Questions

1. The Arctic Goose Habitat Working Group recommended that the eastern arctic greater snow goose population be held between 800 000 and 1 million birds by 2002. This reduced population would still be 15 to 20 times greater than the population in the late 1960s.
   (a) What are some consequences of the population remaining so large?
   (b) Discuss some ways in which reductions of geese populations may be achieved.
2. In a group, brainstorm and discuss challenges that biologists encounter in estimating population characteristics for wild populations of
   (a) whales that migrate along the western coasts of North and South America;
   (b) algae that live in water bodies receiving excess fertilizers in runoff from cropland;
   (c) caribou that inhabit an Arctic tundra environment; and
   (d) amphibians that live in marshes.
3. A 1998 study of grizzly bears in the Kananaskis area estimated the population size at 48 to 56 individuals. The study area encompassed 4000 hectares.
   (a) Use these values to determine maximum and minimum density estimates for the population.
   (b) Researchers examined the DNA of hair samples they collected during their field work. How might the analysis of DNA be of value in estimating the size of the bear population?
4. Biologists sometimes measure fish densities using the number of individuals per kilometre of stream. In a study of juvenile bull trout in Eunice Creek, Alberta, the density was observed to increase from less than 50/km in 1984 to over 600/km a year later. Approximately how many more fish were there in 1985 in a section of creek 0.5 km long?
5. The northern leopard frog is one of Alberta's species at risk. It has a highly clumped distribution and is restricted to isolated wetlands supporting very small populations. How might both the isolation and small population sizes of this species threaten its long-term viability?

22.2 Measuring and Modelling Population Change

An ecosystem has finite biotic and abiotic resources at any given time. Biotic resources, such as prey, vary in availability. Some abiotic resources, such as space and light, vary little, while others, such as temperature and water availability, vary greatly. There is, therefore, a limit to the number of individuals that an environment can support at any given time. The carrying capacity of an ecosystem is the maximum number of organisms that can be sustained by available resources over a period of time. You can review these concepts in Chapter 4.

Carrying capacity is dynamic, since environmental conditions are always changing. Two populations of the same species of fish, for example, might occupy quite different ecosystems with different carrying capacities, due to biotic and abiotic variations in the environment. A large, nutrient-poor, oligotrophic lake (**Figure 1 (a)**) could have a smaller carrying capacity per unit area than a much smaller, nutrient-rich eutrophic environment (**Figure 1 (b)**). In this case, the population density of fish in the oligotrophic lake would be much lower than that of the fish in the eutrophic lake.

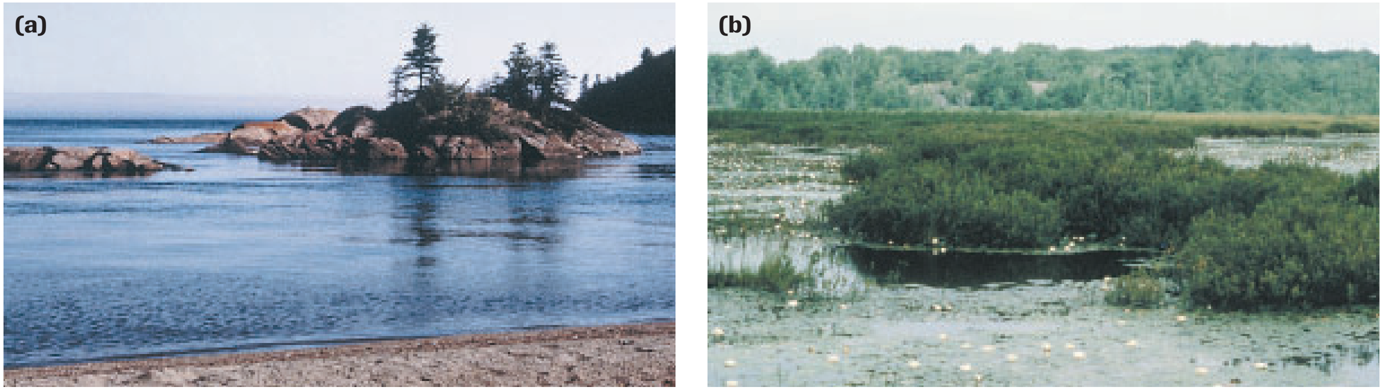

Figure 1
Carrying capacity is determined by the environment in which a population lives. The population size in the oligotrophic lake **(a)** might be limited by available food, while the population size in the eutrophic lake **(b)** might be limited by available space.

When populations increase in size, the amount of resources available per individual decreases. When populations change in density, their new density may exceed the available supply of resources. A variety of factors influences how rapidly populations can grow before they meet or exceed the carrying capacity of their environment.

natality the number of births per unit of time

mortality the number of deaths per unit of time

immigration the number of individuals that move into an existing population per unit of time

emigration the number of individuals that move away from an existing population per unit of time

Factors That Affect Population Growth

Populations are always changing. Depending on the species and on environmental conditions, populations experience natural hourly, daily, seasonal, and annual fluctuations in numbers. Population size can change when individual organisms are added to the population through births or removed through deaths. Population size may also increase when individuals immigrate and decrease when individuals emigrate. The main factors that affect population growth, measured per unit of time, are **natality** (the number of births), **mortality** (the number of deaths), **immigration** (the number of individuals that move into an existing population), and **emigration** (the number of individuals that move away from an existing population). These factors may vary from species to

species. For example, the females of some species have the potential to produce very large numbers of offspring in their lifetimes. Each female of many species of starfish, for example, can lay over 1 million eggs per year. In contrast, a female hippopotamus may have the potential to give birth to just 20 young in an entire lifetime of 45 years. For any organism, the maximum reproductive rate that could be achieved under ideal conditions is called the biotic potential. You can review the factors that determine biotic potential in Section 4.4 of this textbook. Biotic potential is an inherited trait, and so can be acted on by natural selection. Human actions can also affect birth, death, immigration, and emigration rates in populations.

DID YOU KNOW ?

Biotic Potential

Consider the biotic potential of a single *Escherichia coli* (*E. coli*) bacterium on a hamburger patty. Under ideal conditions, *E. coli* can reproduce by binary fission every 12 min. After 12 min there are two bacterial cells, and after 24 min there are four cells. If this doubling continued unchecked for the next 24 h, there would be enough *E. coli* cells to cover the entire surface of Earth to a depth of more than 1 m!

Determining Changes in Population Size

Population ecologists often need to quantify changes in population growth in order to monitor and evaluate these changes. Mathematical models provide the underlying foundation for this science.

The number of individuals in a population is given by the variable ***N***. The change in the number of individuals in a population, **Δ*N***, can be calculated from natality, mortality, immigration, and emigration, using the following equation:

N a variable describing the number of individuals in a population

Δ*N* a variable describing the change in the number of individuals in a population

$$\Delta N = [\text{natality } (n) + \text{immigration } (i)] - [\text{mortality } (m) + \text{emigration } (e)]$$

If the number of births plus immigrants is higher than the number of deaths plus emigrants, the population will have positive growth, increasing in size. Conversely, if the number of deaths plus emigrants exceeds the number of births plus immigrants, the population will experience negative growth, decreasing in size. If the number of births plus immigrants equals the number of deaths plus emigrants, the population is said to have zero growth and will remain a constant size.

While measuring ΔN is of great value, population ecologists are often more interested in the **growth rate** (***gr***), which describes how quickly a population is increasing or decreasing—the change in population size per unit of time. The population growth rate is given by the formula:

growth rate (***gr***) the change in population size per unit of time

$$gr = \frac{\Delta N}{\Delta t}, \text{ where } \Delta t \text{ represents the change in time (often measured in years)}$$

The growth rate is often expressed as a **per capita growth rate** (***cgr***) and represents the change in population size, ΔN, relative to the initial population size, N.

per capita growth rate (***cgr***) the change in population size relative to the initial size of the population, per unit time

$$cgr = \frac{\Delta N}{N}$$

The usefulness of per capita growth rate is clear when comparing populations of different sizes. For example, a population of 2000 individuals that grows by 40 in 1 year has a growth rate of 0.020, while a smaller population of only 200 individuals, with the same increase in numbers (40), experiences a dramatic growth rate of 0.20. Per capita growth rate may also be expressed as a percentage, by multiplying it by 100 ($cgr \times 100$).

SAMPLE exercise 1

Over 2 years, a population of 900 experienced 66 births and 14 deaths. Five individuals left the population and 13 individuals joined the population. Using this information, determine

(a) the population change

(b) the new population size

(c) the growth rate

(d) the per capita growth rate

Solution

(a) We are given the following variables:

change in time, $\Delta t = 2$ years

initial population size, $N = 900$ individuals

natality, $n = 66$ individuals

immigration, $i = 13$ individuals

mortality, $m = 14$ indiviuals

emigration, $e = 5$ individuals

The required variable is population change, ΔN. It can be determined from equation

$$\begin{aligned}\Delta N &= [(n) + (i)] - [(m) + (e)] \\ &= [66 \text{ individuals} + 13 \text{ individuals}] - [14 \text{ individuals} + 5 \text{ individuals}] \\ &= 60 \text{ individuals}\end{aligned}$$

The population change, ΔN, is 60 individuals.

(b) From the given information, we know that the initial population size, N, was 900 individuals. We determined the change in population size, ΔN, in part (a). The new population size is the sum of these values.

$$\begin{aligned}N + \Delta N &= 900 \text{ individuals} + 60 \text{ individuals} \\ &= 960 \text{ individuals}\end{aligned}$$

The new population size is 960 individuals.

(c) The required variable is growth rate, gr. We know the change in time, Δt, from the given variables. We determined the change in population size, ΔN, in part (a). The growth rate is determined from the equation

$$\begin{aligned}gr &= \frac{\Delta N}{\Delta t} \\ &= \frac{60 \text{ individuals}}{2 \text{ years}} \\ &= 30 \text{ individuals/year}\end{aligned}$$

The growth rate is 30 individuals per year.

(d) The required variable is per capita growth rate, cgr. We were given the initial population size, N. We determined the change in population size, ΔN, in part (a). The per capita growth rate is determined from the equation

$$\begin{aligned}cgr &= \frac{\Delta N}{N} \\ &= \frac{60 \cancel{\text{ individuals}}}{900 \cancel{\text{ individuals}}} \\ &= 0.067\end{aligned}$$

Learning Tip

When solving a problem involving a calculation, a good strategy is to start by identifying the given variables and the required variable.

Learning Tip

Exact numbers, like the number of individuals in this question, are considered to have an infinite number of significant digits. You can review the rules for determining significant digits in Appendix A7, Math Skills.

Since the population change took place over 2 years, then the per capita growth rate is 0.067 per 2 years. To get the per capita growth rate per year, we therefore must divide 0.067 by 2.

$$\frac{0.067}{2\text{ years}} = 0.0335 \text{ per year}$$

The per capita growth rate per year is 0.0335.

Practice

1. Complete **Table 1** by calculating the missing values.

Table 1 Measured and Calculated Factors Describing Four Different Populations

	Initial population (N)	Time period (Δt)	Births (n)	Deaths (m)	Immigrants (i)	Emigrants (e)	Population change (ΔN)	Growth rate (gr)	Per capita growth rate (cgr)
(a)	600	2	20	15	25	10			
(b)	200	4	40	60	10	0			
(c)	3000	1	450	350		100	150		
(d)	1000		180	160	30	40		5	

2. The human population has a per capita growth rate of approximately 0.012 per year. If the human population is 6 billion, determine
   (a) the change in population per year
   (b) the change in population per day

Population Growth Models

Scientists studying wild populations often use such mathematical models, based on data collected in the field. Models can provide a visual tool to help researchers see patterns in past population changes and predict future population change. For example, population ecologists may use plots of the past growth rate of a population over time to predict future increases or decreases in the population of a species at risk.

The growth of a population also depends on whether the population is open or closed. An **open population** refers to a population that is influenced by the factors of natality, mortality, emigration, and immigration. Most wild populations are open, since they have the ability to immigrate and emigrate between populations that exist in different locations. In a **closed population** immigration and emigration do not occur so only natality and mortality determine population growth. Closed animal populations are rare. Land-based populations on secluded islands, such as the Peary caribou herd that inhabits an Arctic Ocean island, can be thought of as closed because they have no easy means to travel to other populations. (The animals are able to move between islands in winter.)

We will explore two common models of population growth, exponential growth and logistic growth. For both these models, it is assumed that immigration is equal to emigration, so only natality and mortality are considered. This would be similar to a closed population.

When a population increases by **exponential growth**, the population size increases by a fixed rate over a fixed time period. This rate is denoted by the variable ***r***. A population will only grow exponentially when its ecosystem has an unlimited supply of the biotic and abiotic resources it needs, such as food, light, space, and water. Under these

open population a population in which change in number and density is determined by natality, mortality, immigration, and emigration

closed population a population in which change in size and density is determined by natality and mortality alone

exponential growth a pattern of population growth in which the population size increases by a fixed rate per a fixed unit of time

r a variable indicating the rate of increase of a population experiencing exponential growth; *r* is limited only by the biotic potential of the organisms in the population

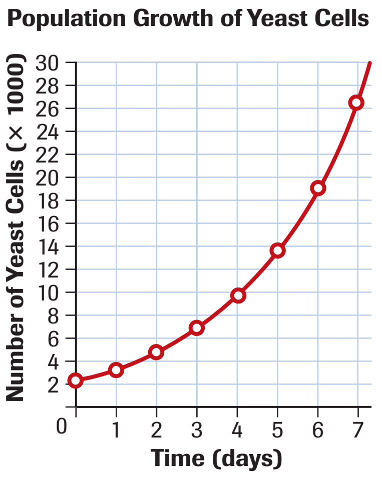

Figure 2
Exponential growth curves are always J-shaped.

conditions, the only limit on population growth is the biotic potential of the individuals making up the population.

During exponential growth, natality is always higher than mortality. Therefore, each successive generation of a population will have more individuals and more offspring than the previous generation. For example, let's assume that the initial size of a yeast cell population is 3000 yeast cells and that 10 % of the cells die each generation. The cells in the starting population divide to produce 6000 offspring, of which 600 die. Reproduction of the remaining 5400 cells gives 10 800 offspring, of which 1080 die. The next generation would then be 21 600 cells, of which 2160 would die, and so on. You can see how population size increases very rapidly during exponential growth. When population size versus time is plotted for a population undergoing exponential growth, the resulting graph is always J-shaped, as shown in **Figure 2**. Therefore, if a researcher has data that gives a J-shaped curve, she or he knows that the population is growing exponentially.

Notice that in **Figure 2**, the exponential growth curve is smooth. This is because yeast cells reproduce throughout the year, as do many other species (including humans). However, many species reproduce only at a particular time of the year. For example, harbour seals in northern British Columbia breed only between May and June. In these species, population size typically increases very quickly during the breeding season and then drops. Therefore, population size must be measured at the same time each year (such as June of each year) to accurately determine population size changes. If the ratio between natality and mortality remains constant, the size of the population will increase in steps over time (**Figure 3 (a)**).

Population biologists are often more interested in long-term growth patterns than in short-term seasonal fluctuations. Population growth graphs for species that reproduce only at specific times are therefore usually drawn as smooth curves, which show changes in average population size over time (**Figure 3 (b)**).

EXTENSION

Population Growth Curves
Listen to this discussion of why population size increases gradually during the early stages of a population's growth.

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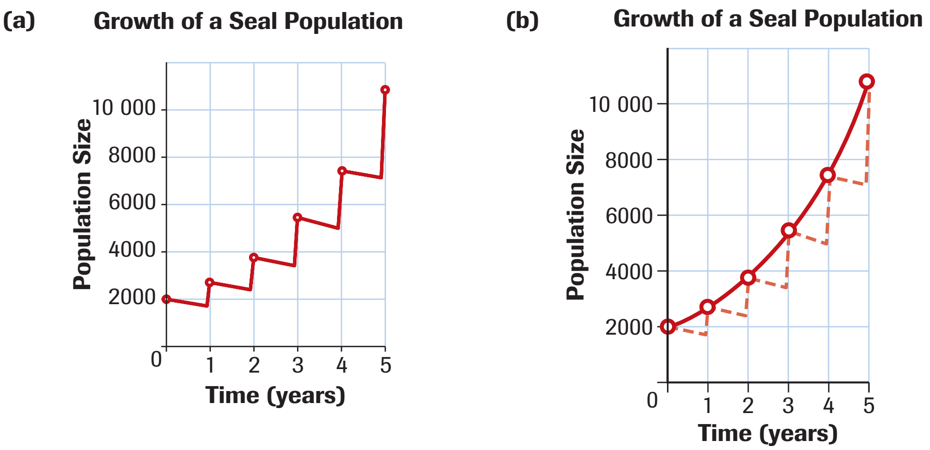

Figure 3
(a) The size of the seal population size was determined several times each year. There are sharp increases when reproduction occurred, followed by declines in numbers.
(b) Drawing the graph as a smooth curve shows the long-term trend in average population size.

For any population growing exponentially, the time needed for the population to double in size is a constant. The **doubling time** (t_d) of the population can be estimated by the following formula:

doubling time (t_d) the time needed for a population that is growing exponentially to double

$$t_d = \frac{0.69}{cgr}$$

The value 0.69 is a constant. For example, if a population has a per capita growth rate of 2.0 % per year (0.020), the approximate time needed for the population to double would be $\frac{0.69}{0.020}$, or 35 years (to two significant digits).

SAMPLE exercise 2

A population of 2500 yeast cells in a culture tube is growing exponentially. If the per capita growth rate, *cgr*, is 3.0 % per hour, calculate

(a) the time it will take for the population to double in size

(b) the size of the population after each of four doubling times

Solution

(a) We are given the following variables:

number of individuals, $N = 2500$ individuals

per capita growth rate, $cgr = 3.0\ \%$ or 0.030 per hour

The required variable is population change, t_d. It can be determined from equation

$$t_d = \frac{0.69}{cgr}$$

$$= \frac{0.69}{0.030 \times \frac{1}{\text{hour}}}$$

$$= 23 \text{ hours}$$

The yeast population will double in size every 23 hours.

(b) The size of the population after four doubling times can be determined using a table, as shown in **Table 2**.

$t_d = 23$ hours, initial population size is 2500

Table 2 Change in Yeast Cell Population Size

Doubling times	Time (hours)	Population size
0	0	2500
1	23	5000
2	46	10 000
3	69	20 000
4	92	40 000

Practice

3. After the rainy season begins in the tropics, a small population of mosquitoes exhibits exponential growth. The initial population size is 980 and the per capita growth rate is 34.5 % per day.

(a) Calculate the doubling time for the population.

(b) How many doubling times will have to pass in order for the population to exceed 2 000 000? How many days is this?

CAREER CONNECTION

Ecologist

Ecologists study a wide range of subjects, all of which involve the relationships of living organisms to each other and to their environments. Ecologists are often particularly interested in population size and population growth characteristics. Ecologists plan and conduct field research and long-term studies to find life history patterns, and develop recommendations on wildlife management. Are you interested in a career as an ecologist?

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Learning Tip

Remember to follow the rules for significant digits in your answers. You can review these rules in Appendix A7.

environmental resistance any factor that limits a population's ability to realize its biotic potential when it nears or exceeds the environment's carrying capacity

logistic growth a model of population growth describing growth that levels off as the size of the population approaches its carrying capacity

lag phase the initial stage in which population growth rates are slow as a result of a small population size; characteristic of geometric, exponential, and logistic population growth

log phase the stage in which population growth rates are very rapid; characteristic of geometric, exponential, and logistic growth

stationary phase the phase in which population growth rates approach zero as the population size reaches the carrying capacity and stabilizes; the defining characteristic of logistic population growth

K a variable indicating the number of individuals in a population at the carrying capacity of an environment

The exponential model of population growth assumes that a population will continue to grow at the same rate indefinitely. This implies that the population has continuous access to an unlimited supply of resources. Of course, an unlimited resource supply is never the case in the real world. Any ecosystem has a limited supply of biotic and abiotic factors to support the organisms in it. Eventually, resources will become scarce.

However, when a population enters a new ecosystem, abiotic and biotic resources are often plentiful. Initially, there may be only a few individuals, so the initial growth rate may be slow. However, since population growth isn't limited by resources, the population size will increase exponentially. Eventually, however, the population size will approach the carrying capacity of the ecosystem, and resources such as food, water, light and space will begin to limit population growth.

The influence of biotic and abiotic factors that limit the size of a population is called **environmental resistance**. As environmental resistance increases, the growth rate of the population slows until natality and mortality become about equal. At this point, the size of the population stabilizes. This pattern of population growth is called **logistic growth**. This model of population growth fits most closely with population growth patterns seen in nature.

If you graph logistic growth, the curve resembles the letter S. As a result, it is referred to as an S-shaped or sigmoidal curve, which has three distinct phases (**Figure 4**). The first, called the **lag phase**, occurs when the population is small and is increasing slowly. The second phase, called the **log phase**, occurs when the population undergoes exponential growth. As available resources become limited, the population experiences increasing environmental resistance and cannot continue rapid growth; therefore, the population's reproduction slows and the number of deaths increases. This is the **stationary phase**, which occurs at or close to the carrying capacity of the environment. The size of the population when it has reached the carrying capacity is indicated by the variable ***K***. At the stationary phase, a population is said to be in dynamic equilibrium, because the number of births equals the number of deaths, resulting in no net increase in population size.

Logistic growth can be seen in a population of fur seals on St. Paul Island, Alaska. In 1911, fur seal hunting was banned since the population had become extremely low. Since their numbers were so low, the seals had many unused resources to support the recovering population. The population grew rapidly until it stabilized around its carrying capacity, as shown on **Figure 5** on the next page.

EXTENSION

Factors Contributing to the End of Exponential Growth

Why does exponential population growth end? Find out more by listening to this description of what happens as a population nears the carrying capacity and its rate of growth slows.

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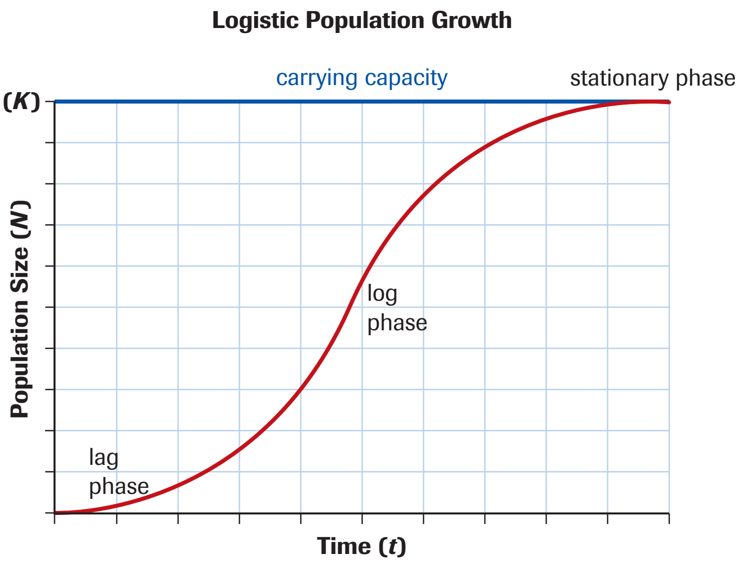

Figure 4
The logistic growth model results in a sigmoidal (S-shaped) curve.

The logistic growth model works for populations growing under suitable conditions, but fits few natural populations perfectly for two main reasons: no population exists by itself, and many interactions occur among the members of a single population.

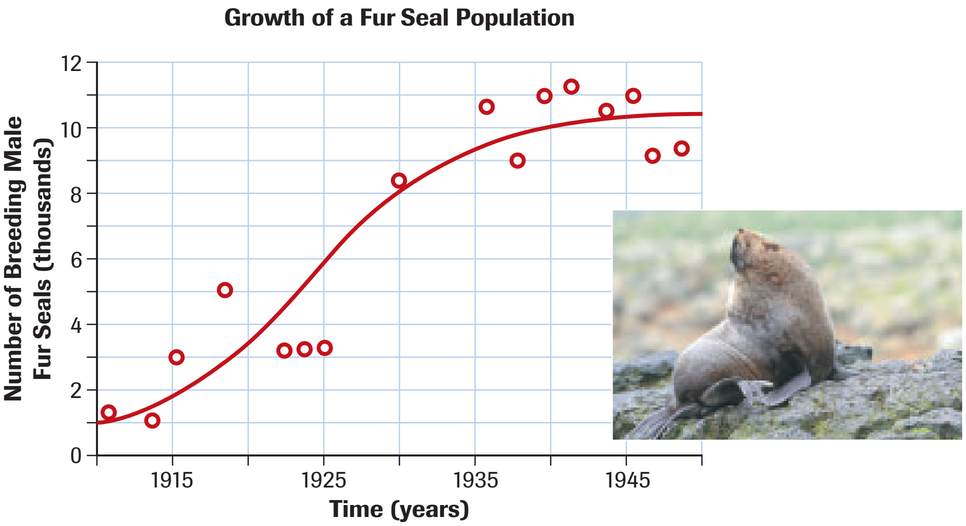

Figure 5
A population graph from 1910 to 1950 for fur seals on St. Paul Island, Alaska

mini *Investigation* — *Blogs in a Bottle: Population Growth in a Finite Environment*

The size of most populations fluctuates over short periods, but remain relatively stable over long periods of time. However, under certain environmental conditions, populations may be able to grow steadily and often rapidly. Such populations eventually reach or exceed the carrying capacity of their environments and their growth ceases.

In this activity, you will model the growth of an imaginary population that lives in a large but finite environment. The Blog population has a constant *cgr* and doubles in size every five days. Blogs can only live in a bottle.

Materials: water (Blogs), eye dropper, graduated cylinders (small and large), large bottle

Predict the number of doubling times it will take for the population of Blogs to completely fill their bottle (reach their maximum sustainable population size).

- Place the starting population (one drop of water) in the bottle. Record the population size in a data table.
- Add a second drop of water to represent the passing of five days. Record the time and total population size.
- Add enough water to again double the total size of the population. Record your values.
- Repeat the above step until the bottle is completely full or you have run out of time.

Note: When the total population size reaches 16 drops, you may convert your measurements to millilitres. One millilitre is roughly equivalent to 16 drops.

(a) Plot a graph of population size versus time. If you have access to a spreadsheet program, use it to tabulate your data and generate the graph.

(b) How many doubling times did it take for the Blogs to completely fill their bottle?

(c) Was your prediction/hypothesis correct? Were you surprised by the results?

(d) If the Blogs found three new environments—three similar empty bottles—how many more doubling times would it take to completely fill all four bottles?

(e) Examine your graph. During what span of time would the Blogs not have worried about running out of space? In other words, when do you think the Blog population might have first realized they had little time left at their current growth rate?

SUMMARY Measuring and Modelling Population Change

- Mathematical models are used to predict trends in population growth.
- Exponential growth demonstrates growth limited only by biotic potential.
- Logistic growth, limited by carrying capacity, is most like the population growth patterns seen in wild populations.

Section 22.2 Questions

1. Researchers studied a population of 34 peregrine falcons for one year to analyze the effect of pesticides on population growth. In the first three months, 57 eggs were laid. Owing to thin shells suspected to have resulted from pesticide damage, 28 eggs broke. Of the remainder, 20 hatched successfully (**Figure 6**). However, nine baby falcons died from severe birth defects. During the next 6 months, 11 birds died as a result of direct pesticide exposure, and 8 were captured and taken to a conservation area. During the last three months, four birds migrated into the area. Determine the population growth of peregrine falcons in this study.

Figure 6

2. The growth rate for a population of 90 field mice in 6 months was 429 %. If the number of births was 342, the number of deaths was 43, and there was no emigration, determine the number of mice that migrated into the field.
3. In practising both agriculture and forestry, humans attempt to maximize productivity of the plants they are harvesting. For example, the application of herbicides on crops and tree plantations helps reduce competition from other plant species. Describe additional ways in which farmers and foresters help domesticated and harvested species approach their biotic potential.
4. In many rural areas, stray cats are a problem as they may return to being wild (also known as feral). Feral cats that have not been spayed or neutered can reproduce, which may result in a population of feral cats. One pair of cats can produce 12 kittens in 1 year. If half these kittens are female, this increased population could potentially produce 84 kittens in the second year. In 5 years, the population could reach almost 33 000 feral cats.
   (a) Identify the kind of growth that is occurring.
   (b) Outline the conditions that would have to be in place for the population to achieve its biotic potential.
   (c) Describe various types of environmental resistance that might restrict the feral cats from reaching their biotic potential.
5. A biologist determines the growth rate of a population of 198 frogs in a marsh near Beaverhill Lake, Alberta, to evaluate the quality of the environment. The researcher finds that, in one year, 34 were born, 86 died, 12 migrated into the marsh, and there was no emigration.
   (a) Determine the growth rate, *gr*, and the per capita growth rate, *cgr*, of the population.
   (b) Do you think that tracking the population growth rate of one population of frogs over one year in this marsh is adequate to make a conclusion about the environment? Explain your reasoning.
6. Scientists monitored the population size of a species newly introduced to an ecosystem. Their data are in **Table 3**.

Table 3 Population Size of Species X

Year	Population size	Year	Population size
1999	44	2003	301
2000	56	2004	275
2001	132	2005	321
2002	224	2006	298

   (a) Sketch a graph of the data. Identify the form of growth curve of the species.
   (b) Predict the long-term impact on population size if a second group of 44 individuals were added to this population in 2007.
   (c) Use your graph to estimate the number of individuals in the whole population when it has reached the carrying capacity of the ecosystem (*K*).

Factors Affecting Population Change 22.3

In 1993, zebra mussel populations in the lower Illinois River, which had exploded to a density of nearly 100 000 per square metre, were causing significant harm to aquatic ecosystems. The zebra mussels were severely depleting the amount of dissolved oxygen available to the entire ecosystem, and increasing competition for food resources. The resulting conditions were stressful for other species, but also affected the survival of the zebra mussels. Scientists observed a dramatic decline in these populations. Researchers now believe that the increased density of the zebra mussel population led to increased competition among members of the population (**Figure 1**).

Figure 1
Competition for resources among zebra mussels will eventually limit growth in these populations.

Density-Dependent Factors

With an increase in population size—for example, after young are born—the population density of the species increases. High density results in adverse conditions. Some individuals may find it difficult to obtain food and may emigrate. Others may die. A factor that affects a population only when it has a particular density is called a **density-dependent factor**. Such a factor limits population growth. Charles Darwin recognized that the struggle for available resources within a growing population would inherently limit population size. This struggle for survival involves such factors as competition, predation, disease, and other biological effects.

When the individuals of the same species rely on the same resources for survival, **intraspecific competition** occurs. As population density increases, intraspecific competition increases, so the population's growth rate slows. This intraspecific competition can have a pronounced effect on the reproductive success of individuals, as shown in the example in **Figure 2**. As competition for food increases, the amount of food per individual often decreases. This decrease in nutrition results in a decrease in an individual's growth and reproductive success. Harp seals, for example, reach sexual maturity when they have grown to 87 % of their mature body weight. When the population density increases, each individual seal gets less to eat and gains weight more slowly than it would if the population density were lower. As a result, the seals reach sexual maturity at a slower rate, which decreases the potential number of offspring they might have.

density-dependent factor a factor that influences a population at a particular density

intraspecific competition an ecological interaction in which individuals of the same species compete for resources in their habitat

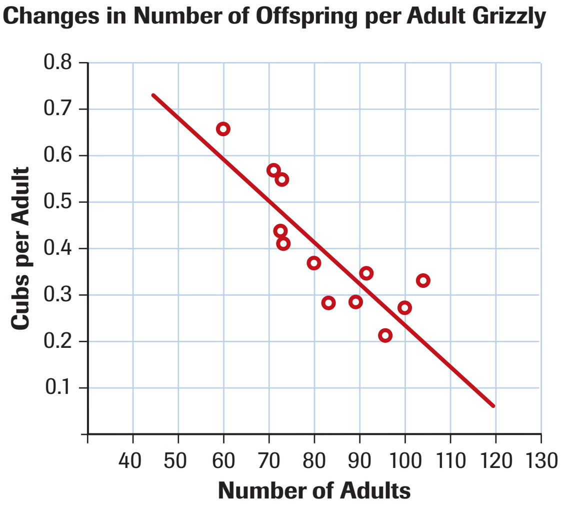

Figure 2
As population density increases in this grizzly bear population, the number of cubs per adult decreases.

predation an ecological interaction in which a predator (a member of one species) kills and consumes prey (usually a member of another species)

minimum viable population size the smallest number of individuals needed for a population to continue for a given period of time

Figure 3
Minimum viable population size is only a prediction. The whooping crane did not become extinct, even when there were only 23 birds left.

density-independent factor a factor that has the same influence on a population at any population density

Figure 4
Swainson's hawks are decreasing in numbers as a result of pesticide use.

Another major density-dependent factor that limits population growth is **predation**, the consumption of prey by predators. If a prey species has a large, dense population, intense competition for limited food may result in individuals with poorer health. These individuals are easier for the predator species to catch.

Disease can also be a significant density-dependent factor that limits population size. In dense or overcrowded populations, pathogens are able to pass more easily from host to host. The population declines in size as a result of increased mortality. The overcrowding of farm animals can lead to the spread of disease, such as foot-and-mouth disease in cattle and avian flu in poultry. In 2000, in the *Proceedings of the National Academy of Science*, researchers Wesley M. Hochachka and André A. Dhondt reported the spread of a common poultry pathogen, *Mycoplasma gallisepticum*, in North America through the house finch, *Carpodacus mexicanus*. They showed a relationship between population size and the incidence of the disease, concluding that the spread of this disease was density-dependent.

Some density-dependent factors reduce population growth rates at low densities. A small population size can result in inbreeding and the loss of genetic variation, which can threaten a population's continued survival. The **minimum viable population size** is the smallest number of individuals that ensures the population can persist for a given amount of time. The minimum viable population size consists of enough individuals so that the population can cope with variations in natality and mortality as well as environmental change or disasters. The minimum viable population size varies among species. Scientists use it as a model to estimate the size at which a population would be considered at risk. In 1941, biologists were concerned that the whooping crane would become extinct, since the wild population worldwide had decreased to 21 birds, and only two birds were in captivity (**Figure 3**). Hunting of the birds for meat and eggs, as well as disturbance of their wetland habitats in Wood Buffalo National Park in Canada and along the Texas coast in the United States, had reduced the number of whooping cranes to well below the minimum viable population size predicted by biologists. An ambitious breeding program, along with legal protection of the whooping crane and its winter and summer habitats, have restored the population of wild and captive birds to nearly 300, although the species is still considered endangered.

Density-Independent Factors

Populations may also experience changes in size that are not related to population density. **Density-independent factors** can limit population growth through changes in environmental conditions. For example, certain species of thrips, a small insect considered a common plant pest, feed on so many plant species that food supply is rarely a limiting factor. Cooler temperatures, however, reduce the reproductive success of these species. With a reduced birth rate, the population size declines. With the return of warmer temperatures, reproductive success improves and populations expand once again.

Insecticide application is a density-independent factor caused by human actions. The lethal effects of the pesticide exist whether the population has two organisms or two million. Swainson's hawks migrate between the grasslands of the Canadian prairies and Argentina (**Figure 4**). Wildlife biologists noted a drastic decrease in the population of these birds throughout North America, but had not found the cause. It was suspected that many of these hawks hunted for insects, mostly grasshoppers, in farmers' fields. Argentinian fields were regularly sprayed with highly toxic pesticides to control the grasshopper population and preserve the crops for human food. These particular pesticides are banned in North America.

In 1996, 12 Swainson's hawks were captured in Alberta and tagged with satellite transmitters before they migrated to Argentina. Biologists flew to the migration destination to observe the tagged birds and counted more than 5000 dead hawks, killed from pesticide exposure either directly or through the food chain. Some of the pesticides have now been banned in Argentina, and the numbers of Swainson's hawk are beginning to recover.

Limiting Factors and Population Size

Any environmental factor, whether it is density-dependent or density-independent, can be the limiting factor of an ecosystem. Of all the resources that a population requires for growth, the resource in shortest supply is called the limiting factor, and it determines how much the population can grow. For example, a plant population requires nitrogen, carbon dioxide, and sunlight in order to grow (**Figure 5**). If it uses up all available nitrogen, it can no longer grow, even if there is still an abundance of sunlight and carbon dioxide. In this case, nitrogen is the limiting factor. Limiting factors prevent populations from achieving their biotic potential, and determine the carrying capacity of the populations.

EXTENSION

Population Biology

In this Virtual Biology Lab, you can manipulate variables to explore the relationships between population size, environmental carrying capacity, birth rate, and death rate in a population.

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(a)

(b)

Figure 5

Plants need many different resources for growth and survival. The resource in shortest supply is considered the limiting factor to growth. The orange hawkweed plants in **(a)** are flourishing while the plants in **(b)** are limited by available space.

INVESTIGATION 22.1 ***Introduction***

Measuring Population Changes

Duckweed is a tiny flowering plant that floats in clusters on the surface of freshwater ponds. In this investigation, you will design and conduct experiments to test the influence of environmental factors on the growth rate of a duckweed population. You will also estimate the carrying capacity of the environment.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

To perform this investigation, turn to page 758.

EXPLORE an issue

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Carrying Capacity Changes in a Warm Arctic

In February 2005, Alexander Wolfe and Neal Michelutti, researchers at the University of Alberta, published their findings on climate change. As part of a 16-member team of scientists from Canada, Norway, Finland, and Russia, the researchers studied changes to populations of microscopic algae and primary consumers in the High Arctic and came to the conclusion that “the biology is starting to change.”

Canada’s Arctic landscape is one of the most beautiful, pristine, and harsh environments on Earth. Species diversity is limited, many population sizes are small, and population densities are often low. The extremely cold winters, shifting pack ice, and permafrost have all been major limiting factors that have prevented the vast majority of species from inhabiting this vast ecosystem. Meanwhile, these same physical conditions have created an environment in which a very special group of species has evolved. Polar bears, arctic poppies, arctic char, and narwhals all call the Arctic their home. These species and many others survive the long harsh winters and reproduce successfully during the long summer days. The Arctic is also home to Inuit, who have flourished in this environment for thousands of years.

But this environment is changing: the Arctic is warming. Until recently, most of the attention regarding climate change and global warming has focused on physical data—temperature changes, pack ice and permafrost melting, sea-level changes, and changing weather patterns. Now, data and observations are emerging that highlight the impacts on living systems (**Table 1**).

1. Suggest one or more specific environmental limiting factors that may be responsible for each of the changes shown in **Table 1**.
2. When an environmental factor changes, is the result always detrimental to living organisms?
3. Why are major environmental changes more likely to benefit species that do not normally live in the region, and more likely to harm species that are native to the region?
4. Populations of many Arctic species are small and have low densities. How might these factors make them more vulnerable to change?
5. Conduct library and Internet research to become more aware of the impact of climate change on Inuit in Canada. How does climate change threaten their traditional way of life?

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Table 1 Observed Changes in Populations Living in Arctic Regions

Species	Changing population parameters
ivory gulls	Rapid and dramatic 80 % decline in populations nesting in the High Arctic.
various	Expanding home ranges. Insects such as the yellow jacket wasp, mammals including cougar and mule deer, and birds such as the rose grosbeak and dusky flycatcher are all appearing in northern communities for the first time.
insect pests	The spruce bark beetle has devastated 300 000 ha of forest in Canada’s Kluane National Park, Yukon. The spruce budworm now appears only 400 km south of the Arctic circle.
trees	Trees are growing faster, as evidenced by thicker tree rings in trees sampled in the Mackenzie River delta.
polar bears	Reductions in pack ice are forcing polar bears to swim farther to reach their seal-hunting grounds. Some scientists predict that summer pack ice may be completely gone in a matter of decades.

Environmental Stability and Population Change

The amount of change in an ecosystem also affects the growth of populations. In a stable ecosystem, the amounts and types of abiotic and biotic factors remain very similar over time. Undisturbed boreal forests, such as can be found in Jasper National Park, are stable ecosystems. In unstable ecosystems, factors in the ecosystem undergo rapid, unpredictable change. A boreal forest that is being logged is an example of an unstable ecosystem. Different organisms have different reproductive strategies, and natural selection favours different strategies in these two types of ecosystems.

Recall from the previous section that *K* is the number of individuals in a population at the carrying capacity of its ecosystem. ***K*-selected organisms** have traits that adapt them to living in a population at or near to the carrying capacity of their ecosystem. They are most often found in a stable environment. The most significant trait of *K*-selected organisms is their reproductive strategy. They produce only a few offspring and devote large amounts of parental resources ensuring those offspring survive. *K*-selected organisms are usually large, with long life-spans. Their offspring tend to be slow-growing and require a lot of parental care. They have a low biotic potential, so the size of populations of *K*-selected organisms tends to change slowly. When the number of *K*-selected organisms in an ecosystem becomes too high, competition between individuals soon becomes intense, reducing the survival rate and limiting the number of adults available to breed. The overall population is therefore maintained close to the carrying capacity. Large mammals such as elk, bears, and humans are *K*-selected species (**Figure 6 (a)**).

***K*-selected organism** an organism that is adapted to survive at or near the carrying capacity of its environment

The variable *r* represents the rate of increase of a population experiencing exponential growth. The genetic traits of ***r*-selected organisms** allow them to increase their population size rapidly. These organisms are most often found in unstable environments. The reproductive strategy of *r*-selected organisms is to produce many offspring and devote very little parental resources to their survival. They are usually small in size, have a short life-span, and have a high biotic potential. When environmental conditions are favourable, a population of *r*-selected organisms can grow very quickly, with competition not usually being a significant factor. Conversely, a change to unfavourable environmental conditions can result in deaths. Many insect species are *r*-selected organisms (**Figure 6 (b)**).

***r*-selected organism** an organism that is adapted to increase population size rapidly

(a)

(b)

Figure 6

(a) Humans are *K*-selected organisms. Each individual is capable of producing relatively few offspring and invests a lot of time and resources in their care.

(b) Mosquitoes are *r*-selected organisms. Each individual is capable of producing hundreds of offspring, and invests little in their care.

CAREER CONNECTION

College, Technical, or Vocational Instructor

Studying population change and community dynamics requires many technical skills. Much of this training can be gained at a college or a technical or vocational institution. Instructors at these schools teach various subjects, including hands-on laboratory and research techniques. If you enjoy the idea of combining skills in science with teaching and training, this may be a good career for you.

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The general characteristics of these two classes of organisms are summarized in **Table 2**.

Table 2 General Features of *K*-selected Species and *r*-selected Species

K-selected species	*r*-selected species
live in predictable, stable environments	exploit rapidly changing environments
long-lived	short-lived
population size stable	population size highly variable
density-dependent mortality	density-independent mortality
competition intense	competition low
multiple reproductive events beginning later in life	single reproductive event at a young age
prolonged parental care of young	little or no parental care of young
modest numbers of offspring	very high numbers of offspring
tend to have an S-shaped population growth curve	tend to have a J-shaped population growth curve
large body size	small body size

SUMMARY Population Change

- Density-dependent factors affect a population only at particular population densities.
- The influence of density-independent factors is the same regardless of population density.
- *K*-selected organisms tend to be found in stable environments. Their reproductive strategy is to produce fewer offspring and devote significant parental resources to ensure their survival.
- *r*-selected organisms tend to be found in unstable environments. Their reproductive strategy is to produce many offspring and devote few parental resources to them.

Section 22.3 Questions

1. Explain the difference between density-dependent and density-independent factors.
2. Classify the following scenarios as density-dependent or density-independent:
   (a) A forest fire destroys a great deal of habitat in Jasper National Park.
   (b) Many aquatic organisms die as a result of adverse weather conditions during the breeding season.
   (c) A young aggressive hawk invades the geographic range of established hawks, driving weaker birds from the geographic range.
3. Identify one density-dependent and one density-independent limiting factor that were not discussed in this section. Explain how they might affect the growth of a population.
4. Differentiate between *r* and *K* population growth strategies. Give at least two examples of each.

5. Study the graph in **Figure 7** which shows a population of the great tit, a European bird similar to the chickadee. The graph illustrates population density versus clutch size (the number of eggs to be hatched at one time).
   (a) Is this a case of density-dependent or density-independent regulation?
   (b) Draw a corresponding graph to illustrate population density versus food supply. Explain the reasoning behind the shape of your graph.
6. For each example in **Figure 8**, determine whether the population is made up of *r*-selected organisms or *K*-selected organisms. Justify your answer using the characteristics listed in **Table 2**.

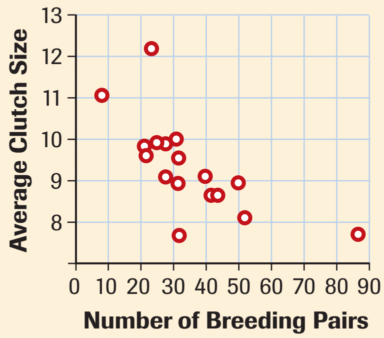


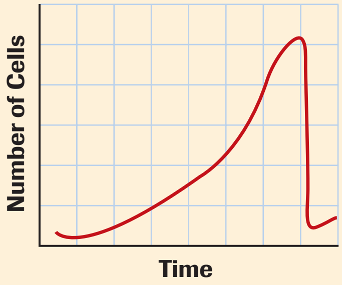
Figure 7

(a) Galapagos tortoise

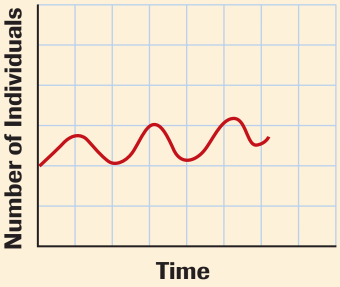
(b) pioneer succession plant species or large insect swarm

(c) rabbit

(d) **Bacteria Growing in a Glass of Milk**



(e) **Population of Coyotes in a Large Parkland**



(f) **An Introduced Species in a New Environment**

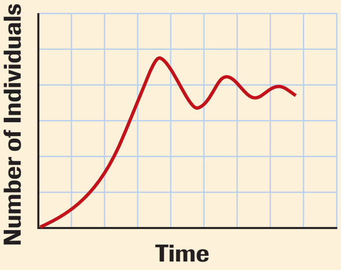


Figure 8

INVESTIGATION 22.1

Measuring Population Changes

Duckweeds, among the smallest of all flowering plants, are free-floating, aquatic plants that form green mats on the surfaces of freshwater ponds. One plant consists of a single leaf-like structure with a single tiny root hanging down. Duckweeds can grow and reproduce (asexually) rapidly as each new leaf breaks off and forms a new plant. In this investigation, you will test the influence of environmental factors on the population growth rate of duckweed. You will also estimate the carrying capacity of the environment.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Materials

duckweed plants
plastic cups or 150 mL beakers
pond water
liquid fertilizer (optional)
artificial light source and timer (optional)
water bath or other suitable heat source

Design

With your group, design experiments to test the influence of an environmental variable on the growth rate of a duckweed population and to estimate the carrying capacity of the experimental environment. You may choose from a wide variety of variables such as temperature, nutrient availability, or light intensity. Base your estimate of carrying capacity on the size of population that can be sustained in one container. Be sure to obtain your teacher's approval of your selected variable(s) and experimental design before beginning the experiment.

Note that in order to measure the carrying capacity of the environment directly, the duckweed population must be allowed to grow for an extended period of time. However, it may be possible to generate a crude estimate of carrying capacity by extrapolating graphic data.

Your design must include one or more testable hypotheses; proper selection of independent and dependent variables as well as control(s); a set of procedures and data collection tables; and criteria for analyzing your data, including tracking the changes in population size, density, and growth rate.

Analysis and Evalution

(a) What effect, if any, did the environmental variable have on the growth of the duckweed population?

(b) Was the effect of the variable density-dependent or density-independent? Explain your reasoning.

(c) Describe the growth patterns of your duckweed populations. Did they follow a recognizable or predictable pattern?

(d) Would you describe the duckweed as having an "*r*" or "*K*" reproductive strategy? Explain.

(e) Would you expect your chosen variable to be a limiting factor in natural duckweed populations? Explain your reasoning.

Synthesis

(f) "Environmental factors can eventually limit the maximum size of any growing population." Explain why this statement is undeniable.

(g) No environment is infinite. How did the "cup environment" in your experiment model planet Earth?

(h) If nutrients and light were readily available, the duckweed population in a small container could probably continue to grow until it was limited by physical space. Do you think the same is true of the human population on Earth?
  (i) What do you think is/are the key factor(s) that will eventually limit human population growth?
  (ii) Estimate Earth's carrying capacity for the human population, which is currently more than six billion.
  (iii) Many scientists, economists, and organizations (such as the United Nations) predict that Earth's human population will stop growing late in this century. Conduct research to find out their predictions for the final stable population size.

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EXTENSION

Age Structure Diagrams

Age structure diagrams depict the number of individuals in a population in different age groups. The relative size of age groups can affect the population growth rate. If all other conditions are the same, the population with the highest number of individuals of reproductive age will grow the fastest. This animation shows age structure diagrams for various countries, including Canada.

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Chapter 22 SUMMARY

Outcomes

Knowledge

- describe and explain, quantitatively, factors that influence population growth (22.2)
- describe the growth of populations in terms of the mathematical relationship among carrying capacity, biotic potential, environmental resistance, and the number of individuals in the population (22.1, 22.2)
- explain the different population growth patterns (22.2)
- describe the characteristics and reproductive strategies of *r*-selected and *K*-selected organisms (22.3)

STS

- explain how concepts, models, and theories are often used in interpreting and explaining observations and in predicting future observations (22.2, 22.3)

Skills

- ask questions and plan investigations (22.2, 22.3)
- conduct investigations and gather and record data and information (22.3)
- analyze data and apply mathematical and conceptual models by: designing and performing an experiment or computer simulation to demonstrate the effect of environmental factors on population growth rate (22.2, 22.3)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

22.1

population size
population density
ecological density
population dispersion
clumped dispersion
uniform dispersion
random dispersion

22.2

natality
mortality
immigration
emigration
N
ΔN
growth rate (gr)
per capita growth rate (cgr)
open population
closed population
exponential growth
r
doubling time (t_d)
environmental resistance
logistic growth
lag phase
log phase
stationary phase
K

22.3

density-dependent factor
intraspecific competition
predation
minimum viable population size
density-independent factor
K-selected organism
r-selected organism

Key Equations

- population density: $D_p = \frac{N}{A}$ or $D_p = \frac{N}{V}$
- population change:
  $\Delta N =$ [natality (n) + immigration (i)] – [mortality (m) + emigration (e)]
- population growth rate: $gr = \frac{\Delta N}{\Delta t}$
- per capita growth rate: $cgr = \frac{\Delta N}{N}$
- population doubling time: $t_d = \frac{0.69}{cgr}$

MAKE a summary

1. Select a microorganism, plant, or animal and consider its role and functions as an individual and as a part of a population. Describe its life in terms of
   - current population status
   - intraspecific interactions within the population
   - potential changes to population status and size
   - factors that might affect the population growth
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 22
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Chapter 22 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix D5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Most wild populations exhibit
A. random distribution patterns
B. clumped distribution patterns
C. uniform distribution patterns
D. continuously changing distribution patterns

2. Researchers discovered that when populations are large, female arctic ground squirrels run low on food resources and stop reproducing. This is an example of
A. an *r*-selected reproductive strategy
B. a density-dependent factor
C. a change in biotic potential
D. a density-independent factor

3. NR Tree density was determined in a stand of aspen. The tree count was 6400 stems in 3.8 ha. Determine the density of the stand. (Record your answer to two significant digits.)

4. Which statement best describes carrying capacity?
A. the maximum number of individuals of all species that can live in an area
B. the maximum number of individuals of one species that can live in an area
C. the maximum number of individuals of all species that can live continuously and sustainably in an area
D. the maximum number of individuals of one species that can live continuously and sustainably in an area

5. A population of grouse was counted over the years. When graphed, the population size grew rapidly, peaked, and then fluctuated year over year. Which is true of the population?
A. Grouse cannot increase exponentially.
B. The population followed a typical logistic growth pattern.
C. The population appeared to be made up of *r*-selected organisms.
D. The population size fluctuates once it reaches the environment's carrying capacity.

6. Which of the following is *not* a density-dependent factor?
A. predation
B. disease
C. drought
D. intraspecific competition

7. NR A population is growing exponentially at a rate of 14 % per year. How many years will it take for the population to double in size? (Record all two digits of your answer.)

8. A sudden environmental change to a habitat generally favours
A. *K*-selected organisms
B. species that reproduce numerous times in their lives
C. small organisms that are *r*-selected
D. organisms that establish complex symbiotic relationships

9. Which statement is true, if the North American human population is growing at an annual rate of about 0.7 %?
A. The population has effectively stopped growing.
B. The population will soon begin to decline.
C. The population will double in about 100 years.
D. The population will double in about 1000 years.

10. Which of the following represents the correct pattern for a population undergoing logistic growth?
A. lag phase, log phase, stationary phase
B. stationary phase, log phase, lag phase
C. log phase, lag phase, stationary phase
D. lag phase, stationary phase, log phase

11. NR Determine the density of a population of southern flying squirrels, if 940 squirrels were counted in a 68 ha area. (Record your answer to two significant digits.)

Part 2

12. Using two examples, **explain** why it is important for scientists to track the population status of Canadian species.

13. **Identify** and **describe** ways in which the decline of resources in an ecosystem can affect the growth rate of a population in that ecosystem.

Use the following information to answer questions 14 to 18.

Scientists conducted a study into the competition between two species of rodents: the woodland jumping mouse, *Napaeozapus insignis,* and the meadow jumping mouse, *Zapus hudsonius.* The meadow jumping mouse is known to be able to exist in both field and forest habitats. Both species of mice are seed feeders. The experimental design included the selection of three approximately 100 ha plots with similar plant cover. Plot 1 (100 ha) supported a population of *N. insignis,* plot 2 (92 ha) supported a population of *Z. hudsonius,* while plot 3 (104 ha) supported populations of both *N. insignis* and *Z. hudsonius.* The populations of mice were monitored over a period of 4 years (**Table 1**, next page).

Table 1 Experimental Data of Mouse Populations

	Plot 1 (100 ha)	Plot 2 (92 ha)
Mouse species	*N. insignis*	*Z. hudsonius*
year 1	632	345
year 2	788	461
year 3	840	509
year 4	671	328
	Plot 3 (104 ha)	
Mouse species	*N. insignis*	*Z. hudsonius*
year 1	610	102
year 2	559	188
year 3	663	173
year 4	601	80

14. **Determine** the average population density for each population in each plot over the four-year study. DE

15. Based on these results, what can you **infer** regarding the interactions between these two rodent species? DE

16. **Identify** the type of interaction occurring in plot 3. DE

17. Some biologists might argue that the evidence from this study is inconclusive due to the assumptions being made by the researchers. **Identify** three such assumptions and criticize the acceptability of each. DE

18. **Describe** the improvements that could be made to the experimental design used in this study. DE

19. Six ground finches began nesting on an island in 1990. Biologists monitored numbers in this population for nine years, compiling their data as shown in **Table 2**.
    (a) **Graphically** show the changes in this population over the nine-year period. Label the various population growth phases on your graph.
    (b) **Determine** an estimate of the carrying capacity of the island. Label this value on your graph.

Table 2 Data on Ground Finch Population

Year	Population	Year	Population
1990	18	1995	477
1991	35	1996	359
1992	58	1997	296
1993	170	1998	283
1994	280		

20. **Outline** the elements of the prairie ecosystem that were affected by the depletion of the buffalo herds on the Great Plains of the U.S. and Canada. Consider flora, fauna, and humans as essential elements in your answer.

21. **Table 3** shows the population of Alberta from 1901 to 2003. Write a unified response addressing the following aspects of the population changes over this time: DE
    - **Graphically** present the population data for the province of Alberta shown in **Table 3**. Use a spreadsheet program or graphing calculator, if possible.
    - **Identify** the decade during which per capita growth rate appears to be greatest. Does this rate of growth appear to be sustainable? **Explain**.
    - Use your graph to **determine** an estimate of Alberta's population in 50 years. Do you think this population size will be reached? **Justify** your response.
    - During the past 100 years, Alberta's population increased in size by almost 70 times. **Determine** an estimate of the population size if it increased another 70 times in the next 100 years.

Table 3 Population of Alberta

Year	Population (thousands)	Year	Population (thousands)
1901	43	1960	841
1911	247	1965	910
1920	360	1970	1 046
1925	375	1975	1 227
1930	459	1980	2 179
1935	513	1983	2 345
1940	547	1994	2 705
1945	565	1997	2 838
1950	623	2001	2 975
1955	717	2003	3 164